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A STUDY OF LOOM ACTIONS

AFFECTING WARP YARNS

A THESIS

Presented to

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by

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A STUDY OF LOOM ACTIONS

AFFECTING WARP YARNS

Approved:

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Date Approved by Chairman: ______________________________

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A STUDY OF LOOM ACTIONS AFFECTING WARP YARNS

SUMMARY

The efficiency of a textile weave room is determined primarily by the effectiveness of the size compound used on the warp yarns. The purpose of this size compound is to protect the individual filaments or fibers from the harsh abrasive actions of the loom. The newer synthetic fibers have demanded the introduction of new size compounds for use with the numerous combinations of fiber blends. The result is that an enormous number of size compounds are available, the effectiveness of which is not known.

There is an immediate need for a mechanism which will evaluate these size compounds in terms of their effectiveness as warp yarn sizes. This information is commonly obtained by the expensive method of actually preparing a sized warp and running this warp on a loom. The purpose of this study was to analyze those loom actions which abrade warp yarns and, from this analysis, recommend a method whereby prepared yarns could be efficiently and inexpensively evaluated before they were woven.

For this study a typical loom was selected which was producing a typical fabric satisfactorily. All speeds and settings were adjusted to reproduce a known mill condition. A single-end tensometer was used to determine the various tensions in the warp yarns at several positions on the loom both statically and dynamically. These tensions were measured for both the open-shed positions and the closed-shed position of the harnesses.

Strain gages were mounted on the harnesses of the loom and connected to a strain recorder. Using this setup with the loom operating, the frictional forces between adjacent warp ends were measured. A model of the loom was constructed upon which tests were made to determine the magnitude of the horizontal frictional forces due to the surface contact between the warp yarns and the loom mechanisms. Individual tests were made on the whip roll, the heddles, and the reed to determine the magnitude of their frictional action on the warp yarns.

From the results of these tests, the magnitude and direction of all the abrasive forces acting on the warp yarns, from the loom beam to the fell of the cloth, were determined.

From the results of this study, it is recommended that a mechanism be designed which could reproduce these frictional and tensional actions on a few ends of prepared yarns and evaluate their resistance to loom abrasive actions efficiently and inexpensively. Such a mechanism would be valuable not only to textile mills but also to size manufacturers in testing untried formulas.

CHAPTER I

INTRODUCTION

In the weaving of cloth, warp yarns must be treated in some way to protect them from the stress and abrasive actions to which they are subjected in the weaving process. This treatment consists of the application of an adhesive compound to the warp yarns and is known as sizing.

The advent of the numerous synthetic fibers has made sizing an increasingly important step in the production of cloth. Synthetic fabric producers, working on the assumption that synthetics could be handled in the same way as cotton or silk, have found themselves involved in many costly mistakes. For example, a synthetic filament warp must be sized for reasons entirely different from those for which a spun cotton warp must be sized.[1] A size compound must be selected for spun yarns which will permit them to retain their fuzz until after the weaving process while a compound for continuous filament warp must be one which will penetrate easily between the filaments and bind them together. With the latter, a heavy outside coating would not be needed.

While chemical bonds and chemical affinites are quite important and in some cases fundamental, it is the physical surface factors that are paramount in the application of a size compound to warp yarns.

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[1] F. G. LaPiana, "Rayon Warp Sizing," The Textile Manufacturer, 96:912, pp. 580-2, December 1950.

Warp yarns are sized to hold down the ends of the individual fibers which tend to come to the surface while weaving. The appearance and hand should be changed as little as possible yet enable the warp to be woven sucessfully. The slight loss of fiber that sheds while weaving should be minimized while the sizing process should prevent having single or small groups of filaments face the loom actions unsupported. The size compound selected must be comparatively inexpensive, easy to prepare and apply, and have satisfactory properties with regard to lubricity, toughness of film, strength, flexibility, freedom from static, cohesion, loss of residual elongation, actual penetration, and mildew resistance.

In the manufacture of textiles, size compounds are sometimes used to give weight and body to the fabric, to give a definite finish or handle to the fabric, and to increase the weavability of the warp yarns. In the manufacture of synthetic fabrics the sizing of the warp yarns is done only to bind, strengthen, and smooth the yarn for increased weavability. A weave room operator evaluates a size compound from; 1) the opinion of the weavers, 2) the actual loom efficiency, and 3) the warp breakage counts.[2] A sized warp which has a low breakage count and a low amount of shedding is usually considered to be a well sized warp. The more abrasive actions the warp yarn is subjected to the more end breakage and shedding will occur. Therefore, the abrasive resistance of a sized yarn should be a direct indication of the weavability

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[2] Danial C. Worth, "Abrasion Tests for Sized Yarns," <u>Textile Industries</u>, 116:6, pp. 92-5, June 1952.

of that particular sized yarn.

Frequently an end breaks during weaving because of the manner in which the size compound was applied to the yarn. From actual mill end breakage test, it was found that approximately twenty five per cent of the total breaks were caused by sizing.[3] If an excessive amount of size was applied or if the application of the size was not uniform the abrasive resistance would be decreased and an excessive stiffening of knots and impurities would occur causing adjacent ends to break. Incorrect sizing also produced soft yarn, twisted ends, and taped ends. Of this 25 per cent of breaks that could have been controlled by sizing one-half was due to abrasion. Although all bad warps are not caused by bad sizing, a satisfactory size compound is a necessity in order to produce an undamaged fabric with a reasonable efficiency of production.

Many size problems are due to local conditions. Therefore, size formulas are usually developed to suit local conditions. The selection of the correct size formula has always been a difficult task for the textile mill operator.[4] The entire slashing process becomes very complicated when the stock to be processed is a blend of different materials. In this same manner, and for these reasons, the problems of sizing are numerous and varied.

Recently size manufacturers and chemical companies have produced compounds which are claimed to be well adaptable in the textile

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[3] Ibid.

[4] Raymond Dodson, "Spun-Rayon Warps," Textile World, 95:8, p. 129, August 1945.

industry as size compounds. The problem is that of evaluating these compounds in terms of their ability to make a warp yarn resistant to the abrasive actions of the loom. This evaluating has been done in several ways, a few of which are; 1) producing the size film and testing it for toughness, flexibility, ease of removability, and resistance to probing or abrasive actions, 2) using various abrasion testers to compare abrasion resistances of two or more size compounds, and 3) comparing strength, elongation, and abrasion resistance of sized and unsized yarns both before and after weaving. However, the only true representation of how a sized warp reacts to loom actions was determined by actually running the warp under all weaving conditions. Testing a size compound in this manner is very expensive.

There is an immediate need for a size evaluator which will quickly, simply, and accurately evaluate a size compound or several sized ends of yarn for weavability. This evaluator could be a laboratory type mechanism which would reproduce accurately the loom actions on a small number of sized yarns. There should be a method of calibrating this mechanism or of measuring the abrasion resistance in some units. A testing machine of this type could eliminate the trial and error method of determining a satisfactory size formula. Its use would not be limited to weaving mills but could be used by size manufacturers to test new size ingredients or untried size formulas.

Several abrasion testers which abrade yarns have been produced and have been used to a certain extent. The use of these has been limited to comparing one size compound with another or comparing sized yarns with unsized yarns. The time involved to abrade and test on these abrasion testers has proven to be a disadvantage. Although loom movements have been duplicated on this type of tester, no attempt has been made to duplicate the actual loom action in a definite magnitude. If a tester of this type would abrade sized yarns in the same manner and magnitude as the actions of a loom several properties of that sized yarn could be determined. This test would determine the amount of end breakage, shedding, and damage to the yarn that would occur if that sized yarn were woven on that loom. It would tell whether there would be excessive shedding, excessive end breakage, or good weavability of this size compound on this particular yarn. From these results, size formulas could be selected for certain yarns to be woven under certain conditions without using the expensive and time consuming trial and error method of selection.

The scope of this study is an analysis of the warp yarns under loom operating conditions. The particular loom was selected with a spun cotton sized warp. Speeds, settings, loom parts, and other variable conditions are either typical of mill conditions or typical for the standard fabric being woven.

A kinematic analysis was made of the harness motion which made available all speeds, distances, and accelerations given the warp yarns by the vertical motion of the harnesses. Dynamic analyses were made of the yarns in the form of force diagrams at different positions along the path of the warp from the loom beam to the fell of the cloth.

Several tests were made to determine the direction and magnitude of the frictional forces between the yarn and the loom mechanisms. The frictional forces determined were those at the whip roll, at the drop wires, at the heddles, and at the reed. From these tests, the amount of frictional force produced on one end of warp yarn by these mechanisms was determined in units of grams of friction.

A stress analysis was made of the harness actions in order to determine the amount of force a harness imparts to a warp end when raising and lowering a shed. From this analysis, the amount of friction between an end of yarn being raised and two adjacent ends being lowered was computed in units of grams of friction. Also determined were the angles of flexing and areas of contact of the ends of yarn with the loom mechanisms.

Other tests were made in order to determine what tensions were present in the yarns at different positions of the harnesses and at different positions along the path of the warp. Warp tension was measured at two positions at the rear of the loom. Other tensions were calculated from this data and the friction forces from other tests.

All forces were summarized with the tension forces and resulted in a force diagram of the warp yarn showing all external forces and their approximate magnitude in grams. The conclusion reached was that under the conditions of this test, this force diagram showed accurately the manner in which these warp ends were abraded. This also is a close approximation of the manner in which all warp yarns are abraded during the loom process.

CHAPTER II

THEORY OF ANALYSES

The analysis of the direction and magnitude of the abrasive actions on the warp yarns included not only the various rubbing actions and external forces but the varying tensions in the yarn as well. The various positions for the analyses were selected from a preliminary investigation of the loom mechanisms and the limited amount of literature on the subject.

The most prominent of the rubbing actions between the yarns is the rubbing of the ends on a harness being raised by the ends on a harness being lowered. This action occurred between each pick since the fabric being woven was of a plain weave construction. By recording the tension applied to both the top and bottom of a harness being moved between dwell positions, it was possible to compute the magnitude of the force resisting this movement. From a kinematic analysis of the movement it was concluded that this resisting force was due to three things; 1) the rubbing of these ends between their adjacent ends, 2) the inertia forces due to the varying accelerations present, and 3) the force due to the weight of the harnesses, heddles, harness straps, and yarns. This total resisting force was found while operating the harnesses with the warp and while operating the harness for a second test without the warp. The difference between these resisting forces was concluded to be that resisting force due to the friction on the moving ends.

All warp ends are moved horizontally across the loom. During this movement they are subjected to frictional forces resisting this movement at each position where they contact a fixed loom part or mechanism. This resisting force is present at the whip roll, the drop wires, the heddles, and the reed. A reed, two harnesses of twenty heddles each, four drop wire bars with ten drop wires on each, and the whip roll in its journals from the loom were mounted in the same manner, angles, and distances as they were when on the loom. Forty ends of the yarn from the loom beam were drawn in this model, placed under a definite tension, and pulled over a free turning pulley mounted directly in front of the reed. A weight was applied to the yarn at the rear of the mechanism and a greater weight was applied at the front allowing the warp ends to pass through the model for a definite distance. The time required for this movement was recorded from a stop watch.

As a result of a potential energy change in the mechanism, the work done by the mechanism was equal to the change in kinetic energies within the mechanism plus its frictional losses (Figure 1). Then, the summation of the kinetic energies plus the summation of the work performed by frictional forces was equal to the change in potential energy. The following formula was derived.

$$W_1S - W_2S = KE_1 + KE_A + KE_2 + KE_E + F_AS + F_BS + F_CS + F_DS + F_ES$$

and, $$KE_1 = \tfrac{1}{2} M_1 v^2 \qquad KE_2 = \tfrac{1}{2} M_2 v^2$$

$$KE_A = \tfrac{1}{2} I_A w_A^2 \qquad KE_E = \tfrac{1}{2} I_E w_E^2$$

Where, F = Force of Friction

S = Distance Moved

M = Mass

v = Linear Velocity

w = Angular Velocity

I_A = Inertia of free turning pulley

I_E = Inertia of the whip roll

W_1 = Weight at front of mechanism

W_2 = Weight at rear of mechanism

A = Free turning pulley

B = Reed

C = Harnesses

D = Drop Wires

E = Whip roll

In order to relate v and w to known quantities, the displacement S equals the area A, under the v line on a velocity-time curve.

$$S = \frac{(v_f + v_1)\,t}{2}$$

Letting $v_1 = 0$, $S = \frac{v \times t}{2}$, and $v = rw$,

Where r = radius of a circular shaft. Then,

$$v = \frac{2S}{t} \text{ and } w = \frac{v}{r} = \frac{2S}{rt}$$

The working formula then becomes,

$$W_1 = \tfrac{1}{2}M_1 \times \frac{4S}{t^2} + \tfrac{1}{2}I_A \times \frac{4S}{r_A t^2} + \tfrac{1}{2}M_2 \times \frac{4S}{t^2} + \tfrac{1}{2}I_E \times \frac{4S}{r_A t^2} + F_A + \qquad (1)$$

$$F_B + F_C + F_D + F_E + W_2$$

The whip roll was mounted in its journals. An end of yarn attached to a weight was wrapped around the whip roll to allow no slippage. The whip roll was allowed to rotate from the tension applied to the yarn until the weight on the end of the yarn travelled a definite distance. Again the time for this movement was recorded on a stop watch.

With reference to figure 2,

Change of PE = Summation of KE + Frictional work done

$$W_1S = KE_1 + KE_E + F_ES \text{ or,}$$

$$W_1S = \tfrac{1}{2}M_1 \left(\frac{2S}{t}\right)^2 + \tfrac{1}{2}I_E \left(\frac{2S}{r_Et}\right)^2 + F_ES \qquad (2)$$

The same test and theory were applied to the free rolling pulley and the following formula was derived;

$$W_1S = \tfrac{1}{2}M_1 \left(\frac{2S}{t}\right)^2 + \tfrac{1}{2}I_A \left(\frac{2S}{r_At}\right)^2 + F_AS \qquad (3)$$

By placing the reed between the free rolling pulley and the weight in the above test the following formula was derived;

$$W_1S = \tfrac{1}{2}M_1 \left(\frac{2S}{t}\right)^2 + \tfrac{1}{2}I_A \left(\frac{2S}{r_At}\right)^2 + F_AS + F_BS \qquad (4)$$

By placing a heddle between the free rolling pulley and the weight, instead of the reed, the following formula was derived;

$$W_1S = \tfrac{1}{2}M_1 \left(\frac{2S}{t}\right)^2 + \tfrac{1}{2}I_A \left(\frac{2S}{r_At}\right)^2 + F_AS + F_CS \qquad (5)$$

Using formula (2), I_E and F_E were computed using the values of T and S from two tests and solving two equations for two unknowns.

Using formula (3), I_A and F_A were computed in the same manner.

Using these values of I_A and F_A in formula (4), F_B was computed.

Using these same values found for I_A, I_E, F_A, F_E, F_B, and F_C in formula (1), F_D was computed for one position of the harnesses.

The position of the drop wires is fixed horizontally and changes vertically only slightly with a change in harness position. Similarly, the value of F_D would not change appreciably with a change of harness position. Therefore, the computed value of F_D was used in formula (1) to compute the values of F_C for the level and bottom shed positions of the harness.

Using a Sipp-Eastwood tensometer, the tension on the individual ends of warp yarn was measured at a point between the whip roll and the loom beam and at a point between the whip roll and the drop wires. This tension was measured with the loom operating as well as with the loom inoperative. Using the frictional forces calculated previously, the tension of the yarn at various positions on the loom was calculated.

With reference to figure 1.

$$T_2 = T_1 + F_E, \; T_3 = T_2 + F_D, \; T_4 = T_3 + F_C \text{ and } T_5 = T_4 + F_B$$

CHAPTER III

INSTRUMENTS AND EQUIPMENT

The loom selected for testing was an automatic E model Draper. There were two harnesses used with two plain weave cams. A single shuttle was used to weave the plain weave sheeting (73 ends per inch by 45 picks per inch). The let-off mechanism was the Roper type working with a continuous type take-up. The reed was stainless, 18.42 dents per inch, in which a cotton warp was drawn four ends per dent. Four rows of drop wires were used with the 2810 end warp drawn through in a one-two-three-four order. The whip roll was finished steel, 2.25 inches in diameter. The yarns used were 22s sized cotton for the warp and 26s cotton for filling. The whip roll was set to raise the warp 1¼ inches above the level line of warp from the fell of the cloth to the drop wires. The shed setting permitted the shuttle to pass ¼ inch below the top shed.

An Allis Chalmers induction motor, type AR, 3H.P., 60 cycle, 1.4 amperes, 220 volts, 1760 R.P.M., drove the crankshaft at a speed of 155 R.P.M.

For the harness motion analysis tempered spring steel, 0.500 inches wide and 0.021 inches thick, was riveted to strips of leather and used as harness straps. A Tinius-Olsen Universal testing machine was used to obtain a stress-strain diagram of this metal. Baldwin-Lima SR-4 type A-5 strain gages with a gage factor of 1.99 were cemented to

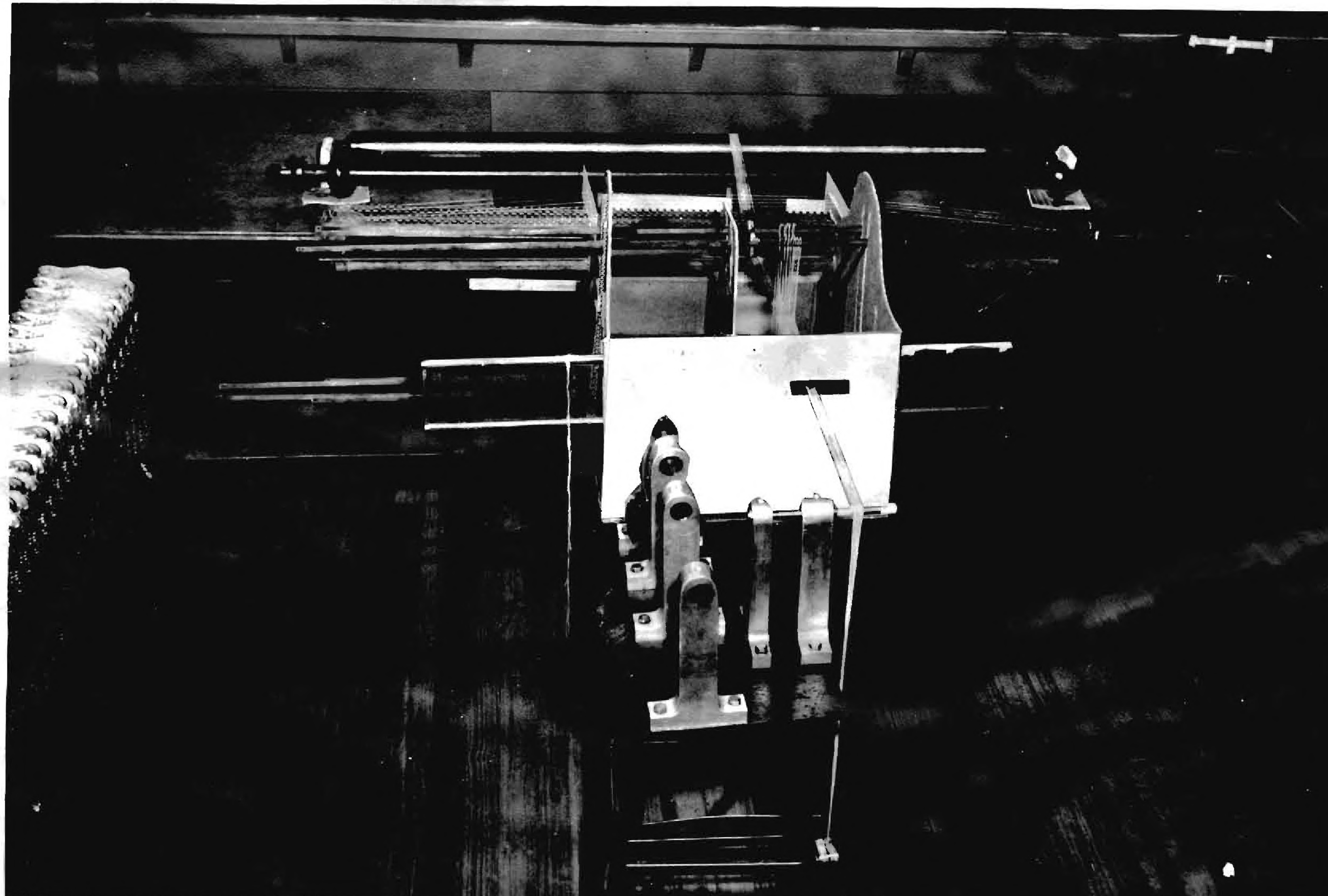

Figure 3. Model Loom.

the metal portions of the harness straps both below and above the harnesses. These gages were connected to a Baldwin SR-4 strain-time recorder. The charts used on this recorder were obtained from the Foxboro Company and were the humidtex type calibrated into micro-inches per inch of strain.

For the friction analysis, a model loom was constructed. Using a rigid corrugated carton for a frame, the reed, the harnesses, and the drop wires from the loom were mounted in the same manner as those on the loom. The whip roll with its journals from the loom was mounted directly behind the model. A small steel shaft was mounted in two one inch Fafnir ball bearings and was placed directly in front of the model. Small holders were constructed which would permit all ends used in the tests to be held under the same tension. These holders were two rubber covered blocks clipped together over the ends of the yarn. Weight holders were constructed and were hooked onto the yarns at the front and rear of the model. Small gram-weights were placed in these holders. A stop watch was used which could be read to one tenth of a second. The yarn used for this test was the 22s sized cotton from the loom beam.

The warp tensions were measured using a Sipp-Eastwood Single End Tensometer calibrated in grams of tension. A holding device was constructed to permit the tensometer to be fixed to the whip roll when reading these tensions.

CHAPTER IV

EXPERIMENTAL PROCEDURE

WARP TENSION ANALYSIS

At the drop wire position, the tension in an end of yarn is the only factor that determines the height at which its drop wire will be raised. The height of all the drop wires on a drop wire bar was measured for three positions of the harnesses to determine the average height a drop wire would be raised by an average tension in the yarn. It was concluded that any warp end which raised its drop wire by this amount was subjected to an average tension.

With the loom inoperative, a warp end was cut from the loom beam, the end was tied to a weight holder, and this holder was allowed to hang freely over the whip roll. Small gram weights were added to this weight holder until the tension in that end of yarn was great enough to raise its drop wire to the predetermined height. The sum of the weights added and the weight of the holder were recorded as the tension on a warp end between the whip roll and the loom beam with the loom inoperative. Several of these measurements were made and the results showed a variation of 50 per cent and more. It was found that since the tension was being applied directly below the whip roll the static friction between the whip roll and the end of yarn was great enough to make the tension results inaccurate.

A single end Sipp-Eastwood tensometer was selected to measure this tension. This tensometer had been accurately calibrated to read tensions in grams. A tensometer of this type is adaptable for use on yarns which are not held firmly on both ends. To use this it must be possible to pass the end of yarn around the pulleys without adding tension to the yarn. A warp end held firmly by the loom beam on one end and by the cloth on the other end does not permit this to be done. The problem encountered was to obtain enough extra length of a warp end to pass this end around the pulleys yet allow the end to remain under its normal tension.

A single warp end was cut from the fell of the cloth and a short end tied to it so that tension could be placed on the end by hand at the front of the loom. This end was released until it could be loosely threaded over the pulleys of the tensometer. The tensometer was mounted over the whip roll to eliminate any inaccuracies due to the static friction at the whip roll. Tension was then applied to the yarn by hand at the front of the loom until this tension was great enough to raise the drop wire to its normal height. The tensometer reading was recorded as the tension in grams of a warp end with the loom inoperative. Since there was no movement of the yarns, no frictional forces were present. This static tension was concluded to be the tension on an end of yarn at any point on the loom. This test was run on an end of yarn for each three inches across the warp and for each of the three positions of the harness through which the warp end was drawn.

A warp end was prepared in the same manner as before but was allowed to flex around the whip roll in the normal manner. The tensometer was placed in a position between the whip roll and the loom beam and again the end was loosely wrapped over the pulleys. Tension was applied by hand as before until the tensometer read the normal static tension. With this tension maintained the loom was power operated for several picks. After stopping the loom the tension was checked with the static value before running the loom again. With the loom operating and the end of yarn under operating tension, the tensometer deflections were recorded as operating tensions. Only maximum and minimum deflections were recorded. From the results of the static tension tests it was concluded that the maximum deflection occurred when the harness was lowered and the minimum deflection occurred while the harnesses were level. This data resulted in dynamic tensional values of warp ends for both open and closed positions of the shed.

This procedure was repeated placing the tensometer between the whip roll and drop wires. A test was made of an end for each three inches across the warp. While obtaining this data for an end, ten values of maximum deflection and ten values of minimum deflection were recorded for each end for both positions of the tensometer.

HARNESS ACTION ANALYSIS

In order to obtain a knowledge of the relationships between the positions of the harnesses and their velocities and accelerations, it was necessary to make a kinematic analysis. Since the harness receives its motion from a treadle moved by a cam an analysis of the cam follower was found to suffice. The cam was being turned at a constant velocity which was measured in revolutions per minute by the use of a speed indicator at the end of the cam shaft. The outer and inner diameters were measured and the design of the change determined. With the use of the following formulas seven values of distance moved, velocity, and acceleration were computed.

$$\text{Distance } S = r - r \cos \theta_h,$$

$$\text{Velocity } V = \frac{dS}{dt} = w_h r \sin \theta_h,$$

$$\text{Acceleration } a = \frac{dV}{dt} = w_h^2 r \cos \theta_h$$

From these values the distance, velocity, and acceleration of the follower were plotted against positions of the harnesses for related curves. From these curves the velocities and accelerations of the harnesses can be obtained for any position of the harness.

Spring steel was selected for use as harness straps on which strain gages could be mounted to accurately measure tension on the top and bottom of the harnesses. To obtain necessary information about this metal it was necessary to construct a stress-strain diagram of it. Fifteen inch strips of the metal were cut in both ends of which three inches of cast iron stock was counter-sunk and set screwed to either side to permit better gripping in the testing machine. A strain gage was mounted on each of the strips with its leads connected to a strain indicator. An identical gage was connected to the dummy side of the wheatstone bridge located in the strain indicator.

Three sets of these specimen were prepared and placed in the Tinius Olsen Universal testing machine. An initial load of ten pounds was applied to the metal to remove any initial bends in the specimen. Load was applied to the specimen in increments of fifty pounds until a load of 250 pounds was applied. Load was then applied in increments of 100 pounds until the specimen broke. Readings of strain were recorded at zero load and at each increment of load. Stress was calculated in pounds per square inch and the strain was recorded in micro-inches of strain. From these values of stress and strain three stress-strain diagrams were constructed from which the modulus of elasticity of the metal was computed.

The averages of three micrometer measurements of thickness and width of the metal strips were used to compute the cross-sectional area.

Short strips of this metal were riveted to strips of leather for use as harness straps. The leather portion was flexed around the circular shaft above the harness and the metal portion connected to the harness. With the harnesses in their level position, A-5 type SR-4 strain gages were glued to the metal portion of these straps after the metal had been cleaned thoroughly to remove any traces of dust, oil, or color. The leads from these gages were connected to the active leads of the Baldwin Strain Recorder. A dummy gage was also connected to the recorder. The needle of the recorder was adjusted to record along a line in the middle of the chart with no strain on the gages so both tensile and compressive strains in the gages could be recorded.

The top left gage on the front harness was connected to the active terminals of the recorder. The loom was operated by power and four minutes of tensions were recorded on the first chart. On this same chart four minutes of tensions on the lower left gage, the top right gage, and the lower right gage were recorded by connecting these gages to the active terminals of the recorder, one at a time, while the loom was at level shed position. The same tests were made on the gages mounted on the rear harness. This procedure was repeated on both harnesses until six charts were obtained.

The warp yarns were cut and removed from the harness heddles and the take-up and let-off mechanisms were disconnected. After the fork knock-off motion was disconnected and the shuttle removed the loom was power operated. These same tension tests were repeated on both harnesses with the warp yarns removed.

From an analysis of the chart deflections it was concluded that the tensile and compressive deflections occurred when the harnesses were passing their level positions. These deflections were greater than any deflection that occurred when a harness was near a dwell position.

From these tests it was concluded that the tensile values to be used from the recorded charts would be those which occurred when the two harnesses pass each other at the level position. From the values of strain obtained directly from the charts the tension in the harness straps while the loom was operating was computed. Knowing all tensions acting on the harnesses, both with and without the warp, the friction between the ends of the harness moving in one direction and the ends of the harness moving in the opposite direction was computed.

FRICTIONAL ACTION ANALYSIS

A rigid corrugated carton was selected for use as a frame for a mechanism which would duplicate the frictional actions of the loom. A reed of the same construction as the reed on the loom previously tested was mounted on the front portion of this frame. Heddle bars with heddles from the harnesses were mounted on this frame in positions which duplicated the position of the harnesses on the loom. These were mounted in a manner which would permit the heddles to be held in either an open or closed shed position. Drop wire bars with drop wires were mounted behind these heddles on the frame at distances duplicating those on the loom. The whip roll and its journals were removed from the loom and placed at the rear of this mechanism at the normal distance and elevation. To reproduce the point of the shed at the fell of the cloth, a small shaft was mounted in two Fafnir one inch ball bearings which were mounted in bearing bushings of a fixed frame. This shaft was elevated to a height representing that of the fell of the cloth directly in front of the reed.

Forty ends of yarn from the loom beam were flexed over the whip roll and drawn through the four rows of drop wires in a one-two-three-four order. These ends were drawn through the heddle eyes in plain weave order. At the reed, the warp ends were drawn in four per dent and the ends flexed over the shaft in the front of the mechanism.

The warp ends at the rear of the mechanism were placed between two small wooden blocks which were covered with rubber strips. These blocks were pressed firmly together by rubber bands. Duco cement was applied around this holder to prevent slippage.

Tension was applied from the front of the mechanism to the ends individually until all ends were under the same tension. This end (at the front of the mechanism) of the warp yarns was held by the same type of holder as the rear end of the warp yarns. Weight holders were attached to both ends of the warp yarns and allowed to fall freely over the shaft and over the whip roll.

The weights selected to apply at the rear of the mechanism were great enough to hold the yarns at a tension approximating that on a loom. The weights selected for use at the front of the mechanism were great enough to instantly overcome the static frictions between the yarns and the individual mechanisms. The difference between the two weights had to be sufficient to pass the yarns through the mechanism with a constant acceleration.

Test Number One--The heddles were placed in the position that duplicated their position on the loom with the front harness raised and the rear harness lowered. A 200-gram weight was placed in the rear weight holder and lowered to a position only a few inches above the floor. A 600-gram weight was placed in the front weight holder and held in a position only a few inches below the shaft. This placed the forty ends of warp yarn under a tension of two hundred grams or five grams of tension per end. The weight at the front of the mechanism was released and allowed to pull the warp ends through the mechanism until the weight holder reached the floor. The time lapse between the instant the weight was released and the instant the weight holder reached the floor was timed by a stop watch calibrated in tenths of seconds. The warp was pulled back through the mechanism to its starting position and the procedure repeated several times until the time lapses began to reach a constant value. This test was repeated using different weights. Similar tests were made with the heddles in their level shed and reversed open shed positions.

When a warp end was broken by the actions of these tests it was removed from the mechanism and the tests were completed on the remaining ends. The data recorded for each of these tests included the number of ends remaining in the warp, the weight applied at the front of the mechanism, the weight applied at the rear of the mechanism, the distance of drop of the front weight, the time lapse of this drop, and the position of the heddles.

Test Number Two--The reed was removed from the mechanism by slipping it over the front end of the warp. Tests were made of the mechanism without the reed, recording time lapses, distance of drop, weights used, number of warp ends, and positions of the heddles. These tests were made for the three positions of the heddles.

Test Number Three--The heddles were removed from the mechanism and the procedure in test number one and test number two was followed. However, the tests were run for the level shed position only. The data received from this test was that data for the mechanism without the reed and harnesses.

The mechanism was dismantled and the individual parts were prepared for testing.

Test Number Four--The small shaft in its bearings was elevated to a position several feet above the floor. An end of the warp yarn was wound around this shaft in a manner to prevent slippage and tied to a small weight holder. A weight was added to the holder and the holder released and allowed to unwind the yarn from the shaft until the weight holder dropped to the floor. The time lapse for this drop was recorded along with the weight used and the distance of the drop. This test was repeated until the results showed the time lapse was reaching a constant value. This procedure was repeated using a different weight.

<u>Test Number Five</u>--Keeping the small shaft in this same position, the end of yarn was drawn from the shaft through a dent in the reed which was mounted directly below the shaft. Then the end was tied to the weight holder directly below the reed. The procedure of test number four was repeated and time of drop, weight used, and distance of the drop were recorded.

<u>Test Number Six</u>--Two ends of warp yarn were wound around the small shaft and connected to the weight holder. Between the shaft and the weight holder, one end was drawn through a heddle eye while the other was allowed to rub against a side of the heddle. This arrangement was made to duplicate not only the friction between an end of warp yarn and its heddle eye but also the friction that that same end is subjected to by rubbing against an adjacent heddle. This heddle was mounted so that the angle of the yarn through the heddle eye would be the angle formed by a heddle on the loom with the harness raised. Again the procedure of test number four was repeated and the data recorded.

<u>Test Number Seven</u>--The whip roll in its journal bearings was mounted in an elevated position several feet from the floor. An end of yarn was wound around the whip roll in a manner to prevent slippage. To this end was tied a weight holder. Gram weights were placed in the holders, the holders were released, and the yarn was allowed to unwind from the whip

roll until the weight holder dropped to the floor. This test was repeated using a different weight. Again, the time of the drop of the weight, the weight used, and the distance of drop were recorded.

CHAPTER V

COMPUTATIONS AND RESULTS

WARP TENSION ANALYSIS

The Sipp-Eastwood Tensometer measured the tensions on the single ends of warp yarn directly. The average tensions determined with the loom inoperative were found to vary with the position of the harness in the following manner: with the harness in level shed position, the tension was found to be 3.67 grams per end, with the harness in the raised shed position, the tension increased to 4.12 grams per end, with the harness in its lowered position, the tension again increased to 10.08 grams per inch. All these values were static values and represent those tensions in warp yarns with the loom inoperative.

The dynamic tension values were also measured directly on single ends of yarn using the same tensometer. Only minimum and maximum deflections were recorded as tensions. From the results of the static tension test, these minimum deflections were concluded to be the tension occurring at level shed position and the maximum deflections concluded to be those tensions occurring when the harness for that end was lowered. The average tension occurring when the harness was lowered was 13.96 grams per end between the loom beam and the whip roll while the average tension occurring between the whip roll and the drop wires with the harness in the same position was 15.05 grams per end. The minimum deflection recorded with the tensometer at both positions on the warp was very

Table 1. Static Tension Values for Warp Ends

Harness Position		Level (Grams)	Up (Grams)	Down (Grams
Test Number				
1		3.9	4.6	11.4
2		2.9	3.1	9.9
3		4.4	4.9	10.9
4		3.9	3.7	10.9
5		3.4	3.9	10.9
6		3.9	4.4	11.9
7		2.9	2.9	9.4
8		3.7	3.9	9.9
9		4.4	4.8	11.9
10		3.9	4.4	9.9
11		3.9	4.4	8.9
12		3.9	4.4	9.4
13		2.9	3.4	8.9
14		3.8	4.4	8.9
15		3.9	4.6	9.4
	Total	55.7	61.8	151.3
	Average	3.67	4.12	10.08

Table 2. Summary of Dynamic Tensions

(Maximum and Minimum Tensions in Grams)

	Position A		Position B	
	Max	Min	Max	Min
	10.4	3.55	19.1	0.0
	24.7	0.00	18.5	0.0
	12.8	0.00	12.7	0.0
	13.6	.90	14.6	0.0
	14.8	.90	12.7	0.0
	12.2	1.30	15.5	0.0
	15.6	0.00	16.1	0.0
	14.1	0.00	14.6	0.0
	13.0	2.10	15.6	0.5
	10.9	0.00	13.5	0.0
	11.3	1.40	16.1	1.3
	12.0	1.90	14.5	1.7
	15.3	.90	15.9	1.0
	14.9	1.80	13.5	1.7
	11.8	1.60	12.9	1.8
Total	209.4	16.35	225.8	8.0
Average	13.96	1.09	15.05	.53

near zero. This led to the conclusion that as these harnesses passed their level position almost all warp tension was released. The difference between the two maximum tensions was found to be 1.09 grams per end. This value was used as a check for the value of the friction force occurring between the yarn and the whip roll.

HARNESS ACTION ANALYSIS

The Baldwin Strain Recorder recorded the strain in the harness straps that occurred when the harness passed its level position. It is at this time during the harness movement cycle that the warp ends on a harness are subjected to a frictional force resulting from the warp ends on the other harness moving in the opposite direction. The harness straps on the harnesses are subjected to a tensile strain at all times but this tension varied with the position of the harness.

The strain gages were mounted on these straps after these straps were placed under an initial strain. Therefore, when these harness straps were subjected to a tension less than this initial tension the recorder measured a strain in a compressive direction.

By observing the deflection of the recording needle it was concluded that: 1) when the front harness was being raised,

The top left, lower left, and lower right gages were placed under compression, and the top right gage was placed under tension.

2) As this harness was being lowered,

The top left, lower left, and lower right gages were subjected to tension while the top right gage was placed under compression.

3) When the rear harness was being raised,

The top left and lower left gages were placed under tension while the top right and lower right gages were under compression.

4) As this harness was being lowered,

The top left and lower left gages were subjected to compression while the top right and lower right gages were under tension.

From the deflections on the chart the tension in each of the harness straps was recorded in units of chart divisions of strain. The difference between the total tension on the top of the harness and the total tension on the bottom of the harness was computed in chart divisions of strain. This difference was attributed to three actions: 1) the force due to the weight of the harnesses, 2) the inertia force due to acceleration, and 3) the force due to the frictions between the ends of yarn.

From the tests on the harnesses with the warp removed the difference between these tensions could only be attributed to 1) and 2) above. Hence, subtracting the difference obtained from the tests without the warp from the difference obtained from the tests with the warp resulted in the force due to the frictions between the yarns in units of chart divisions of strain.

One chart division was equal to 20 micro-inches of strain per inch and the modulus of the metal straps was 29.93×10^6 units. Then, computing the force in pounds,

Force = Stress x Area, where Stress = Strain x Modulus, and

Strain = Chart divisions $\times 20 \times 10^{-6}$, then

Force = Chart divisions $\times 20 \times 10^{-6} \times 29.93 \times 10^6 \times$ Area

The average area was found to be .0108 inches square, therefore, Force = Chart divisions x Constant (6.46488)

These calculations were made for six tests of each harness moving in each direction. The results were immediately corrected to frictional force per end of yarn by dividing the total force per harness by 1405 ends of yarn per harness. The results obtained were:

1) When the front harness was being raised the friction force per end was 2.19 grams. 2) When the front harness was being lowered the friction force per end was 1.54 grams. 3) When the rear harness was being raised the friction force per end was 2.44 grams. 4) When the rear harness was being lowered the friction force per end was 3.54 grams.

Averaging the results above, each end was subjected to a frictional force resisting its movement when a shed was opened of 2.43 grams.

This friction was the result of the ends of yarn rubbing between their adjacent ends and occurred from the fell of the cloth to the drop wire position. This total friction included a friction due to the ends of yarn moving vertically in the reed and a friction due to the ends of yarn rubbing vertically against other heddles.

FRICTIONAL ACTION ANALYSIS

The values of time, distance, and masses from Test Number Four were placed in the formula (2) and two equations were obtained having the two unknowns, inertia of the pulley and frictional force at the pulley. These were solved and the following values obtained:

Inertia $I_A = 0.0166$ and Friction Force $F_A = 5.944$ grams.

The values obtained from Test Number Seven were placed in the formula (3) and two equations were obtained having as unknowns the inertia of the whip roll and the friction force at the whip roll. These were solved and the following values were obtained:

Inertia I_E = 0.0166 and Friction Force F_E = 124.35 grams.

Using these computed values and the results from Test Number Five in formula (4) the following was computed for the frictional force at the reed:

Friction Force F_B = 3.08 grams, 2.81 grams, 3.26 grams or an average of F_B = 3.05 grams per two ends.

These computed values and the values from Test Number Six were placed in formula (5) and the following values obtained for the friction at the heddle eye with the heddle raised:

Friction Force F_C = 12.34 grams, 9.21 grams, or an average of F_C = 10.78 grams per two ends.

These computed values and the values from Test Number One were placed in formula (1) and the following values were obtained for the friction at the drop wires:

Friction Force F_D = 15.46 grams per 40 ends.

Using this value for drop wire friction and other computed values, formula (1) was used with the values from Test Number One (the heddles in level and lowered positions) to obtain the following values for heddle eye friction:

Friction Force (heddles level) F_C = 2.81 grams per end.

Friction Force (heddles lowered) F_C = 6.25 grams per end.

All the above frictional values were converted into grams of friction per end of yarn.

Table 3. Summary of Friction Forces Acting on the Warp Yarns

Horizontal Friction

(Grams per End)

Position	Harness Raised	Harness Level	Harness Lowered
At the Reed	1.53	1.53	1.53
At the Heedles	5.39	2.81	6.25
At the Drop Wires	0.39	0.39	0.39
At the Whip Roll	0.40	0.40	0.40
Total Friction Acting at One Time	7.71 Grams per End	5.13 Grams per End	8.57 Grams per End
Average Total Friction Occurring at Open Shed Position			8.14 Grams per End

Vertical Friction

(Grams per End)

Position	
Front Harness Moving Upward	2.19
Front Harness Moving Downward	1.54
Rear Harness Moving Upward	2.44
Rear Harness Moving Downward	3.54

Average 2.43 Grams per End

CHAPTER VI

DISCUSSION OF RESULTS

The static tensions found on the warp yarns varied greatly with a change in harness position. As shown in Table 1, the tension was greatest at the open shed positions. However, an end on a lowered harness was under a tension twice as great as an end on a raised harness. This difference may be attributed to the elevation of the whip roll. These tensions were measured with the whip roll elevated to raise the warp yarn 1 1/4 inches above the level line from the drop wires to the fell of the cloth. Consequently, had the whip roll been set to level the warp, the tension on a raised end would have been the same as the tension on a lowered end.

The operating tensions listed in Table 2 exceeded the static tensions only by the amount necessary to put the warp into motion. The tensions between the whip roll and the drop wires were greater than those between the loom beam and the whip roll. This difference can be attributed to the frictional force resisting the movement of the warp yarns at the whip roll.

The vertical friction produced between two ends due to the harness motions was accurately measured by the use of strain gages. This rubbing action occurred between the ends over 19 1/4 inches along the length of the yarns, since the yarns from the drop wire to the fell of the cloth were in vertical motion. However, a large portion of this friction occurred at a point on the yarns in the reed. Here, two ends were being raised and two ends were being lowered in a dent which was only 0.054 inches wide. As shown in table 3, this friction was greater on the ends of the rear harness than on the ends of the front harness. The rear harness actually moved a greater distance upward and downward. However, the time for the movements was the same for both the front and rear harnesses. This led to the assumption that the greater the angle of the shed, the more friction occurred between the adjacent ends.

In the frictional action analysis, table 3, the total friction of the whip roll was measured. This total friction was acting in the whip roll journal bearings and was due to two things: 1) the normal force from the weight of the whip roll and 2) the normal force produced by the tensions in the yarns. However, the weight of the whip roll was several times larger than the resulting tensional force. Therefore, the frictional force produced by the yarn tensions was very small in comparison with that produced by the weight of the whip roll. This whip roll friction was a friction which did not vary with the positions of the harnesses.

The frictional force measured for the drop wire position was actually two rubbing actions. The ends of yarn were rubbing not only through their drop wire eyes but also against adjacent drop wires. The data in table 3 shows this drop wire friction as a constant friction. This was an assumption made in order to compute other frictional forces. However, the small movement of the drop wires with the movement of the harnesses would produce only a small variation in this frictional force.

Referring again to figure 3, the frictional forces measured at the heddle eye position were due to similar rubbing actions. However, the results show that much less friction occurred with the harnesses in the level position. On the other hand, the angle the ends made when flexing around a heddle in open shed position must have been great enough to increase the surface contact, increasing the frictional force.

The frictional force measured for the reed represents that force present when passing the warp ends through the dents with the reed fixed. Since speed does not affect the magnitude of frictions, this force would occur while the reed was swinging back toward the rear of the loom. When the reed moved toward the front of the loom this same force would act in the opposite direction, since the reed traveled much faster than the warp ends. Table 3 lists this force and other frictional forces as being constant for all positions of the harnesses. However, this is only true when a continuous type take-up motion is being used.

The actions to which this warp was subjected consisted of both vertical and horizontal frictional forces only some of which varied with the position of the harnesses. These frictional forces are representative, in type, of those occurring on other looms producing fabrics of similar construction.

CHAPTER VII

CONCLUSIONS

By reproducing the loom actions found in this study on prepared yarns, it is possible to evaluate warp yarns in terms of their resistance to loom actions. This evaluation could be very important in the selection of warp size compounds.

Since warp yarns are more easily damaged when a greater tension is applied, the important abrasive actions occur when the harnesses are in their open shed position. End breakage is more likely to occur at this time since almost all warp tension is released when the harnesses are in their level position.

The greatest frictional abrasive action on warp ends occurs as these ends pass through the heddle eyes of the harnesses. However, the frictional actions at the whip roll, the drop wires, the heddle eyes, and the reed occur in succession to any single point on the surface of the warp yarns. Consequently, end breakage is more likely to occur near the reed position.

CHAPTER VIII

RECOMMENDATIONS

It is recommended that a mechanism be designed whereby the abrasive actions determined by this analysis could be reproduced on a single or small group of warp ends. These actions should be reproduced in a multiple of their magnitude which would be representative of actions occurring on a loom over a long period of time. A method should be devised whereby tests could be made on this mechanism to evaluate sized yarns quickly, simply, and accurately in terms of resistance to these abrading actions. This would evaluate yarns in terms of their weavability as warp yarns.

During the performance of this analysis it was found that no instrument was available which would satisfactorally measure warp tensions. It is recommended that a tension measuring device be designed which could be used to determine the running tension of a single warp end.

Size formulas are usually selected to temporarily increase the strength of the warp yarns for the weaving process. The results of this study suggest that size formulas for spun yarns be selected primarily for the smoothness they impart to the surface of the warp yarns. Similarly, whip rolls, drop wires, heddles, and reeds should be selected to provide the smoothest surface contact possible.

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APPENDIX

Table 4. Dynamic Tension Values for Warp Yarns

(Maximum and Minimum Tensions in Grams)

	Position A Max	Position A Min		Position B Max	Position B Min
			Run # 1		
	10	4		22	0
	9	5		23	0
	10	3		17	0
	10	3		17	0
	9	4		24	0
	10	2		28	0
	10	4		21	0
	12	3		12	0
	11	3		13	0
	11	4		14	0
Average	10.4	3.5		19.1	0
			Run # 2		
	26	0		18	0
	26	0		20	0
	24	0		21	0
	25	0		14	0
	26	0		16	0
	23	0		17	0
	24	0		23	0
	22	0		18	0
	25	0		16	0
	26	0		22	0
Average	24.7	0		18.5	0
			Run # 3		
	16	0		15	0
	15	0		10	0
	14	0		13	0
	10	0		12	0
	14	0		11	0
	10	0		11	0
	11	0		13	0
	14	0		12	0
	13	0		11	0
	11	0		19	0
Average	12.8	0		12.7	0

Table 4. Continued

(Maximum and Minimum Tensions in Grams)

	Position A Max	Position A Min		Position B Max	Position B Min
			Run # 4		
	16	1		15	0
	16	1		14	0
	17	1		15	0
	15	0		14	0
	14	1		15	0
	12	1		15	0
	10	0		15	0
	11	1		14	0
	14	1		14	0
	13	0		15	0
Average	13.6	.9		14.6	0
			Run # 5		
	15	1		14	0
	14	0		13	0
	17	1		12	0
	18	1		11	0
	12	0		13	0
	14	2		15	0
	13	1		14	0
	16	0		15	0
	13	0		10	0
	16	1		10	0
Average	14.8	.9		12.7	0
			Run # 6		
	12	1		18	0
	13	2		16	0
	10	2		17	0
	13	2		15	0
	13	0		14	0
	10	1		12	0
	12	2		18	0
	13	2		16	0
	13	1		14	0
	13	0		15	0
Average	12.2	1.3		15.5	0

Table 4. Continued

(Maximum and Minimum Tensions in Grams)

	Position A			Position B	
	Max	Min	Run # 7	Max	Min
	18	0		16	0
	16	0		16	0
	18	0		15	0
	17	0		16	0
	15	0		17	0
	14	0		17	0
	13	0		16	0
	13	0		16	0
	15	0		17	0
	17	0		15	0
Average	15.6	0		16.1	0
			Run # 8		
	13	0		15	0
	13	0		15	0
	14	0		14	0
	15	0		14	0
	15	0		15	0
	16	0		15	0
	16	0		16	0
	9	0		14	0
	16	0		12	0
	14	0		16	0
Average	14.1	0		14.6	0
			Run # 9		
	14	3		16	0
	14	2		15	1
	13	2		17	0
	12	3		15	1
	12	1		16	0
	12	2		16	0
	14	1		15	0
	14	3		15	1
	12	2		15	0
	13	2		16	0
Average	13.0	2.1		15.6	.5

Table 4. Continued

(Maximum and Minimum Tensions in Grams)

	Position A Max	Position A Min	Position B Max	Position B Min
		Run # 10		
	12	0	16	0
	13	0	15	0
	10	0	14	0
	11	0	10	0
	13	0	13	0
	11	0	13	0
	9	0	14	0
	10	0	13	0
	10	0	13	0
	10	0	14	0
Average	10.9	0	13.5	0
		Run # 11		
	10	1	16	2
	11	2	15	1
	10	2	15	1
	11	1	17	2
	12	1	17	1
	10	0	15	2
	11	1	17	0
	12	2	16	1
	13	1	16	1
	13	2	17	2
Average	11.3	1.4	16.1	1.3
		Run # 12		
	11	1	15	4
	12	2	15	2
	13	2	16	3
	14	2	17	3
	11	2	14	2
	12	1	15	2
	11	2	13	1
	12	2	13	0
	13	3	14	0
	11	2	13	0
Average	12.0	1.9	14.5	1.7

Table 4. Continued

(Maximum and Minimum Tensions in Grams)

	Position A Max	Position A Min	Position B Max	Position B Min
		Run # 13		
	16	1	15	1
	16	2	14	2
	16	1	15	1
	15	0	17	1
	14	0	17	1
	15	1	17	1
	16	0	17	1
	16	1	16	0
	14	2	16	1
	15	1	15	1
Average	15.3	.9	15.9	1.0
		Run # 14		
	15	1	15	2
	15	2	14	2
	16	2	13	3
	14	2	12	2
	16	1	13	1
	14	2	14	3
	14	1	14	2
	15	2	15	1
	16	2	12	0
	14	3	13	1
Average	14.9	1.8	13.5	1.7
		Run # 15		
	12	1	14	2
	12	2	13	1
	13	1	12	2
	10	2	13	3
	13	1	12	2
	13	2	11	2
	11	2	12	2
	12	2	13	1
	12	1	14	1
	10	2	14	2
Average	11.8	1.6	12.9	1.8

Table 5. Stress Strain Data From Metal Strip Tests

Specimen A

Load (lbs.)	Strain (Baldwin Type-L Indicator) Range	1000ths	Dial	Strain (Micro-Inches Per Inch)	Stress (p.s.i.)
0	0	10	890	0	0
48	0	10	1185	295	4571.4
100	0	10	1360	470	9525.0
147	0	10	1510	620	14,000.0
200	0	10	1670	780	19,050.0
248	0	10	1820	930	24,615.0
375	0	12	212	1422	35,670.0
500	0	12	595	1705	47,650.0
625	0	12	990	2100	59,509.0
710	0	12	1289	2490	67,620.0

Table 5. Continued

Specimen B

Load (lbs)	Strain (Baldwin Type-L Indicator) Range	1000ths	Dial	Strain (Micro-Inches Per Inch)	Stress (p.s.i.)
0	0	10	1068	0	0
50	0	10	1168	100	4760
100	0	10	1312	244	9530
150	0	10	1468	400	14,280
200	0	10	1627	559	19,050
250	0	10	1788	720	24,810
375	0	12	185	1117	35,700
500	0	12	600	1532	47,600
625	0	12	1038	1970	59,550
725	0	12	1420	2352	69,000

Table 5. Continued

Specimen C

Load (lbs.)	Strain (Baldwin Type-L Indicator) Range	1000ths	Dial	Strain (Micro-Inches Per Inch)	Stress (p.s.i.)
0	0	10	1595	0	
50	0	10	1835	240	4760
100	0	12	009	414	9530
150	0	12	157	562	14,280
200	0	12	304	709	19,050
250	0	12	454	859	24,810
375	0	12	822	1227	35,700
500	0	12	1200	1705	47,600
625	0	12	1608	2013	59,550
650	0	12	1705	2110	61,900

Table 6. Modulus of Elasticity for Metal Strips

Specimen A (p.s.i.)	Specimen B (p.s.i.)	Specimen C (p.s.i.)
27.1×10^6	30.0×10^6	30.2×10^6
27.3×10^6	30.5×10^6	29.3×10^6
27.0×10^6	30.3×10^6	29.4×10^6
27.2×10^6	30.6×10^6	29.4×10^6
27.5×10^6	30.3×10^6	29.3×10^6

Table 7. Measurements for
Cross-sectional Area of Metal Strips

	Strap Position	Thickness (Inches)	Width (Inches)
Front Harness			
1)	Top Left	.0217	.5023
	Top Left	.0219	.5024
	Top Left	.0216	.5024
2)	Top Right	.0214	.5025
	Top Right	.0217	.5025
	Top Right	.0215	.5024
3)	Bottom Left	.0211	.5023
	Bottom Left	.0212	.5030
	Bottom Left	.0215	.5024
4)	Bottom Right	.0215	.5028
	Bottom Right	.0215	.5025
	Bottom Right	.0220	.5028
Back Harness			
1)	Top Left	.0220	.5023
	Top Left	.0215	.5033
	Top Left	.0214	.5027
2)	Top Right	.0215	.5029
	Top Right	.0215	.5029
	Top Right	.0217	.5032
3)	Bottom Left	.0212	.5027
	Bottom Left	.0217	.5026
	Bottom Left	.0215	.5032
4)	Bottom Right	.0214	.5024
	Bottom Right	.0216	.5031
	Bottom Right	.0217	.5026
	Total	.5163	12.0634
	Average	.0215 inches	.5026 inches

Cross-sectional area = .0215 x .5026 = .0108 square inches

Table 8. Summary of Strains
Recorded for Harness Motion Analysis

Front Harness - With Warp (Chart Divisions of Strain)

Chart	Gage	Tension				Avg.	Compression				Avg.
I	1	2.3	2.5	2.4	2.6	2.45	1.8	1.8	1.7	1.6	1.73
	2	4.1	4.1	4.1	4.2	4.13	2.1	2.2	2.2	2.1	2.15
	3	2.0	2.4	2.3	2.5	2.30	3.1	3.0	2.5	3.1	2.93
	4	8.0	7.9	8.1	7.8	7.95	2.1	2.5	2.5	2.4	2.38
II	1	2.1	2.2	2.2	2.4	2.23	2.3	2.0	2.1	2.0	2.10
	2	4.8	4.9	4.8	4.7	4.80	1.7	2.0	1.8	1.7	1.80
	3	3.0	2.9	3.0	3.1	3.00	2.1	2.0	2.2	1.9	2.05
	4	7.7	7.8	8.1	8.0	7.90	1.7	1.6	2.0	2.0	1.83
III	1	2.3	2.4	2.4	2.4	2.38	2.0	2.0	2.0	2.0	2.00
	2	4.9	4.8	4.8	4.8	4.83	2.0	1.9	2.1	2.0	2.00
	3	2.4	2.5	2.3	2.5	2.43	2.3	2.2	2.4	2.4	2.33
	4	7.6	7.4	7.7	7.7	7.60	2.7	2.4	2.2	2.7	2.50
IV	1	2.3	2.2	2.1	2.3	2.23	1.9	2.0	2.0	2.0	1.98
	2	5.0	5.1	4.9	5.0	5.00	1.3	1.2	1.4	1.4	1.33
	3	2.3	2.3	2.2	2.3	2.28	2.9	2.8	2.6	2.7	2.75
	4	8.4	8.0	8.1	7.9	8.10	2.0	2.2	1.9	2.0	2.03
V	1	2.3	2.2	2.3	2.4	2.30	1.9	2.0	2.0	2.0	1.98
	2	4.1	4.0	4.1	4.0	4.05	1.7	1.5	1.4	1.5	1.53
	3	2.3	2.7	2.7	2.7	2.60	2.4	2.5	2.5	2.7	2.53
	4	7.9	7.5	7.8	7.4	7.65	2.4	2.3	2.4	2.5	2.43
VI	1	2.2	2.2	2.2	2.4	2.25	2.0	1.9	2.0	2.0	1.98
	2	5.0	4.9	5.0	4.8	4.93	1.5	1.3	1.3	1.2	1.33
	3	2.8	2.8	2.9	2.8	2.83	2.0	2.1	2.3	2.0	2.10
	4	8.4	7.5	8.0	8.1	8.00	2.2	2.3	2.5	2.5	2.38

Table 8. Continued

Rear Harness - With Warp (Chart Divisions of Strain)

Chart	Gage	Tension				Avg.	Compression				Avg.
I	1	3.2	3.3	3.0	3.2	3.18	3.4	3.6	4.0	4.4	3.85
	2	1.6	1.3	1.2	1.2	1.33	1.8	2.0	2.1	2.1	2.00
	3	1.8	1.9	2.1	1.7	2.13	1.6	1.4	1.8	1.8	1.65
	4	5.0	5.4	5.3	5.1	5.20	1.3	1.3	1.4	1.4	1.35
II	1	3.2	3.1	3.1	3.1	3.13	4.1	4.1	3.7	4.2	4.03
	2	2.1	2.4	2.1	2.3	2.23	1.7	1.6	1.9	1.4	1.65
	3	3.1	3.5	3.7	3.8	3.53	1.7	2.1	2.0	1.9	1.93
	4	4.4	4.7	3.9	4.3	4.33	1.6	1.8	2.0	2.1	1.88
III	1	3.7	3.4	3.6	3.8	3.63	3.2	3.4	3.8	4.0	3.60
	2	2.1	1.7	1.6	2.3	1.93	1.5	1.8	2.0	1.3	1.65
	3	3.2	3.4	3.4	3.3	3.33	1.6	1.8	1.9	1.8	1.78
	4	3.7	3.8	3.4	3.2	3.53	2.2	2.4	2.7	3.0	2.58
IV	1	3.8	3.4	3.8	3.8	3.70	3.2	3.0	3.7	3.4	3.33
	2	2.0	1.7	2.0	1.9	1.90	1.4	2.0	1.5	1.3	1.55
	3	3.8	3.7	3.6	3.3	3.60	1.8	1.8	1.7	1.8	1.78
	4	4.2	4.3	4.3	4.7	4.38	1.2	2.0	1.3	2.1	1.65
V	1	3.1	3.2	3.0	3.2	3.13	3.4	4.0	3.8	4.0	3.80
	2	2.1	2.1	2.2	2.1	2.13	1.7	2.1	2.1	2.2	2.03
	3	3.8	3.5	3.6	3.8	3.68	1.9	2.0	1.8	1.7	1.85
	4	4.0	3.9	4.1	4.0	4.00	1.9	2.0	2.1	1.9	1.98
VI	1	2.9	2.8	3.0	3.0	2.93	4.2	4.0	3.9	3.5	3.90
	2	2.2	1.4	2.0	1.4	1.75	2.0	1.0	1.5	2.0	1.63
	3	3.9	3.5	3.8	3.9	3.68	1.5	1.4	1.4	1.3	1.40
	4	4.4	4.2	4.4	4.2	4.30	1.4	1.9	1.3	1.8	1.60

Table 8. Continued

Front Harness - Without Warp (Chart Divisions of Strain)

Chart	Gage	Tension				Avg.	Compression				Avg.
I	1	2.0	2.0	2.0	2.0	2.00	1.2	1.4	1.5	1.3	1.35
	2	4.3	4.7	5.0	4.8	4.70	1.2	1.0	1.3	1.0	1.13
	3	2.8	2.7	2.5	2.6	2.65	1.3	1.1	1.4	1.3	1.28
	4	5.5	6.0	5.9	5.7	5.78	1.2	1.3	1.0	.8	1.08
II	1	2.2	2.1	2.4	2.3	2.25	1.1	1.1	1.3	1.2	1.18
	2	4.1	4.1	4.3	4.2	4.18	1.4	1.2	1.7	1.8	1.53
	3	3.0	3.2	3.1	3.0	3.08	.5	.9	1.0	1.0	.85
	4	5.8	5.7	6.2	5.8	5.88	1.0	.9	.8	.4	.78

Rear Harness - Without Warp

Chart	Gage	Tension				Avg.	Compression				Avg.
I	1	6.0	6.2	6.3	6.3	4.20	.5	.2	.5	.4	.40
	2	2.8	2.8	2.6	3.0	2.80	1.4	1.7	1.6	1.3	1.50
	3	1.7	1.7	1.6	1.4	1.60	2.1	2.2	2.1	2.2	2.15
	4	4.0	3.7	3.9	4.2	3.95	1.0	1.2	1.1	.8	1.03
II	1	6.8	6.9	6.3	6.7	6.68	1.1	1.0	1.2	1.3	1.05
	2	2.0	1.7	2.1	2.5	2.08	2.0	1.9	2.2	2.2	2.08
	3	1.7	1.9	1.8	1.9	1.83	2.0	2.2	2.1	2.1	2.10
	4	3.7	3.4	4.0	3.5	3.65	1.3	1.6	1.6	1.1	1.40

Table 9. Frictional Data Recorded for Model Loom

Front Heddles Raised

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	39	600	200	33.75	2.2
2	39	600	200	33.75	2.2
3	39	600	200	33.75	2.0
4	39	600	200	33.75	2.0
5	39	600	200	33.75	2.2
6	39	600	200	33.75	2.0
7	39	600	200	33.75	2.4
8	39	600	200	33.75	2.3
9	39	600	200	33.75	2.2
10	39	600	200	33.75	1.9
11	39	600	200	33.75	2.4
12	39	700	200	33.75	1.7
13	39	700	200	33.75	1.8
14	39	700	200	33.75	1.5
15	39	700	200	33.75	1.8
16	39	700	200	33.75	1.7
17	39	700	200	33.75	1.8
18	39	700	200	33.75	1.7
19	39	700	200	33.75	1.7
20	39	700	200	33.75	1.7
21	39	700	200	33.75	1.9

Weight at front = W_1 + weight of end holder, + weight of holder (weight)
Weight at rear = W_2 + weight of end holder, + weight of holder (weight)
Weight of end holder at W_1 = 10.87 grams
Weight of end holder at W_2 = 276.6 grams
Weight of weight holder at front = 13.29 grams
Weight of weight holder at rear = 2.01 grams

Table 9. Continued

Front Heddles Lowered

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	38	700	200	34	2.0
2	38	700	200	34	1.8
3	38	700	200	34	1.8
4	38	700	200	34	2.0
5	38	700	200	34	1.8
6	37	800	200	34	1.4
7	37	800	200	34	1.4
8	37	800	200	34	1.6
9	37	800	200	34	1.5
10	37	800	200	34	1.5
11	37	800	200	34	1.6
12	37	800	200	34	1.7
13	37	800	200	34	1.5
14	37	800	200	34	1.5

Table 9. Continued

All Heddles Level

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	39	500	200	33.75	1.9
2	39	500	200	34	2.9
3	39	500	200	34	2.1
4	39	500	200	33.75	2.1
5	39	500	200	34	2.2
6	39	500	200	34	2.2
7	39	500	200	34	2.0
8	39	500	200	33.875	2.2
9	39	500	200	33.875	2.0
10	39	500	200	33.875	2.1
11	39	500	200	33.875	2.3
12	39	500	200	33.875	2.0
13	39	500	200	33.875	2.1
14	39	500	200	33.875	2.1
15	39	500	200	33.875	2.1

Table 10. Frictional Data
Recorded for Model Loom With Reed Removed

Front Heddles Raised

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	34	600	200	35	1.8
2	34	600	200	35	1.8
3	34	600	200	35	2.2
4	32	600	200	35	2.3
5	32	600	200	35	2.2
6	32	600	200	35	2.0
7	32	600	200	35	2.2
8	31	600	200	35	2.2
9	31	600	200	35	2.1
10	31	600	200	35	2.2

Table 10. Continued

Front Heddles Lowered

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	37	700	200	35	1.2
2	36	700	200	35	1.7
3	36	700	200	35	1.7
4	36	700	200	35	1.8
5	36	700	200	35	1.7
6	36	700	200	35	1.6
7	36	700	200	35	1.7
8	36	600	200	35	1.9
9	36	600	200	35	2.0
10	36	600	200	35	2.0
11	36	600	200	35	2.0
12	36	600	200	35	2.2
13	36	600	200	35	2.0
14	36	600	200	35	1.9
15	36	600	200	35	2.1

Table 10. Continued

All Heddles Level

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	36	600	200	35	1.8
2	36	600	200	35	1.8
3	36	600	200	35	1.8
4	36	600	200	35	1.7
5	36	600	200	35	1.8
6	34	600	200	35	1.6
7	34	600	200	35	2.0
8	34	600	200	35	1.8
9	34	600	200	35	1.8
10	34	600	200	35	1.8
11	34	600	200	35	1.6
12	34	600	200	35	1.6
13	34	600	200	35	1.9

Table 11. Frictional Data Recorded for Model Loom with the Reed and Heddles Removed

Trial	Ends	W_1 (Grams)	W_2 (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	28	600	200	35	1.6
2	28	600	200	35	1.7
3	28	600	200	35	1.8
4	27	600	200	35	1.6
5	27	600	200	35	1.7
6	27	600	200	35	1.5
7	26	600	200	35	1.6
8	26	600	200	35	1.6
9	26	600	200	35	1.6

Table 12. Frictional Data
Recorded for Free Rolling Pulley

Trial	Ends	W (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	1	20	62	3.4
2	1	20	62	3.4
3	1	20	62	3.4
4	1	20	62	3.2
5	1	20	62	3.5
6	1	20	62	3.3
7	1	20	62	3.1
8	1	20	62	2.9
9	1	20	62	3.0
10	1	20	62	3.0
11	1	20	62	3.0
12	1	20	62	3.1
13	1	20	62	3.0
14	1	20	62	3.0
15	1	30	62	2.5
16	1	30	62	2.7
17	1	30	62	2.5
18	1	30	62	2.4
19	1	30	62	2.5
20	1	30	62	2.4
21	1	30	62	2.5
22	1	30	62	2.3
23	1	30	62	2.4
24	1	30	62	2.3

Table 13. Frictional Data Recorded for the Free Rolling Pulley and the Reed

Trial	Ends	W (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	2	20	58	3.8
2	2	20	58	3.5
3	2	20	58	3.6
4	2	20	58	3.4
5	2	20	58	3.4
6	2	20	58	3.4
7	2	20	58	3.3
8	2	20	58	3.2
9	2	20	58	3.2
10	2	20	58	3.2
11	2	20	58	3.2
12	2	10	58	6.6
13	2	10	58	6.7
14	2	10	58	6.7
15	2	10	58	6.9
16	2	10	58	6.8
17	2	10	58	6.5
18	2	10	58	6.8
19	2	40	58	2.0
20	2	40	58	2.1
21	2	40	58	2.1
22	2	40	58	2.2
23	2	40	58	2.1
24	2	40	58	2.0
25	2	40	58	2.1
26	2	40	58	2.2
27	2	40	58	2.1
28	2	40	58	2.2

Table 14. Frictional
Data Recorded for the Heddles

Trial	Ends	W (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	2	30	33	2.8
2	2	30	33	2.7
3	2	30	33	2.8
4	2	30	33	2.5
5	2	30	33	2.5
6	2	30	33	2.4
7	2	30	33	2.2
8	2	30	33	2.5
9	2	30	33	2.4
10	2	30	33	2.3
11	2	20	33	3.6
12	2	20	33	3.8
13	2	20	33	3.6
14	2	20	33	3.5
15	2	20	33	3.5
16	2	20	33	3.4
17	2	20	33	3.4
18	2	20	33	3.3
19	2	20	33	3.3
20	2	20	33	3.3

Table 15. Frictional Data
Recorded for the Whip Roll

Trial	Ends	W (Grams)	Distance of Drop (Inches)	Time (Seconds)
1	1	500	73	2.2
2	1	500	73	2.3
3	1	500	73	2.1
4	1	500	73	2.0
5	1	500	73	2.0
6	1	500	73	2.0
7	1	500	73	2.0
8	1	500	73	2.0
9	1	500	73	2.1
10	1	500	73	2.0
11	1	200	73	2.6
12	1	200	73	2.8
13	1	200	73	2.9
14	1	200	73	2.9
15	1	200	73	2.8
16	1	200	73	2.9
17	1	200	73	2.8
18	1	200	73	3.0
19	1	200	73	2.9
20	1	200	73	2.9